CSRD TR-79-02

Municipal Traffic Control Systems for Ontario Municipalities

Phase I Report

Ontario

Ministry of
Transportation and
Communications

Research and
Development
Division

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SUMMARY

The use of digital computers to control traffic was pioneered in Toronto in the late fifties. In spite of the fact that Toronto has continued to be a leader in computerized control research, Ottawa has been the only other Ontario city to take advantage of the benefits of computer control in the last 19 years.

The MTCS Study was undertaken to examine the needs of small and medium-sized Ontario municipalities for computer control, to estimate the benefits of computer control and to define the most appropriate role for MTC to play in fostering the appropriate use of computer systems.

A questionnaire was distributed to municipalities which indicated that several cities are planning to upgrade their traffic signal control equipment in the immediate future. Several other cities find their systems obsolete and in need of replacement or not sufficiently powerful to cope with growing traffic problems. It is reasonable to assume that it will soon be cost effective for these cities to upgrade their control systems.

After this contact with municipalities a list of system requirements was developed to reflect the perceived needs of Ontario municipalities. In parallel with this activity, data on available traffic signal control systems was assembled and an evaluation of existing systems was undertaken. The current low costs of computer-based traffic signal systems (roughly $5000 per intersection) dictated that this evaluation concentrate on computer technology. A comparison was then made between the perceived needs and the available systems. It was found that a number of off-the-shelf systems exist which can meet the needs of Ontario cities.

There exists, nevertheless, some significant obstacles for municipalities to overcome in procuring cost-effective computer systems. Chief among these is the relative complexity of computer technology and the general lack of familiarity with this technology by municipalities and local consultants.

The study concludes that there is a significant role for MTC to play in providing information and expert advice to municipalities and in co-ordinating a joint procurement of computerized control systems involving municipalities indicating an interest; to date, Oshawa, Kitchener and Brantford. The procurement activities leading to system installations will begin in early 1979 and should lead to fully-operational systems in the three municipalities by mid 1980.

The MTCS Project is expected to lead to substantial traffic control benefits to Ontario municipalities.

1. INTRODUCTION

The Municipal Traffic Control Systems (MTCS) Project was initiated at a time when computer based traffic control systems were being installed primarily in large municipalities. These systems were characterized by their requirement for trained computer operators and programmers and substantial software and hardware development to meet the particular requirements of the end user. Costs were often in excess of $10,000 per intersection. The process of acquiring systems called for much preliminary work prior to procurement which involved the combined efforts of traffic engineers, consultants, and systems engineers. Once contracts had been signed and the work undertaken, severe difficulties in meeting design goals were often encountered. Schedules tended to slip and costs escalate. In the late 60's and early 70's several companies supplying such systems entered and quickly left the field.

This gloomy picture explains in part the reticence of some municipalities to acquiring computer-based systems, even though these systems have the potential of improving the traffic management capabilities of even well-run traffic control offices. The goal of the MTCS Project was to make the acquisition and operation of computer-based traffic signal systems possible for a small to medium-sized municipality. The main obstacles standing in the way of municipalities acquiring such systems were:

1. A lack of standard systems appropriate to the needs and capabilities of medium-sized municipalities.
2. A lack of widespread expertise in the local consulting and traffic engineering community to help define requirements and supervise the acquisition of computerized systems.
3. The prohibitive cost of acquiring systems requiring unique specification preparation and hardware and software development.

In order to overcome these difficulties the following approach was taken in the MTCS project:

1. Investigate the needs and capabilities of Ontario's municipalities in order to determine the essential requirements of any computerized traffic control system.
2. Investigate and evaluate available computerized traffic control systems to determine their applicability to meet the requirements of Ontario municipalities.
3. Prepare a standard system specification for a system that reflects the needs of municipalities and can be supplied by a number of manufacturers without requiring extensive software and hardware development.

4. Implement a system that meets the above specification in one or more Ontario municipalities.

Since the start of the project important developments in the computerized traffic control field have taken place. Computer-based systems have become less complex, less costly and more reliable. Suitable systems are now available off the shelf. Experience gained by manufacturers in their initial installation efforts have led to the evolution of "standard" systems which meet or exceed the requirements of most municipalites.

Total system costs now are in the range of $5000 to $6000 per controlled signal. The systems can be operated by traffic control office staff without previous computer training. The effort required to maintain and operate the systems has become significantly less demanding. Most systems allow unattended 24-hour-a-day, seven-days-a-week operation.

This timely advance in the state-of-the-art of computerized traffic control makes possible, if not unavoidable, the acquisition of such systems by a large number of Ontario municipalities. It is the objective of the MTCS project to assist as many as five or six municipalities in acquiring such systems by mid-1980 by means of joint procurements, co-ordinated by MTC.

This report summarises the work completed to date in this effort. Chapter 2 summarizes the historical development of computerized traffic control and the elements that make up such a system. Chapter 3 explores the benefits of computerized traffic control. Chapter 4 presents findings on the status of traffic control in Ontario based on a questionnaire circulated to over forty Ontario municipalities. Chapter 5 deals with the traffic control requirements of Ontario municipalities based on the questionnaire findings. Chapter 6 contains the summary and evaluation of available traffic control systems. Chapter 7 covers the procurement approach which is recommended to acquire the specified system. Chapter 8 covers conclusions reached by the study staff. Chapter 9 contains the recommendation for Phase II, the demonstration phase of the project.

The recommendations suggest that since a number of municipalities are ready and anxious to upgrade their traffic control systems, a joint procurement be undertaken under the management of a team composed of municipal representatives, consultants and Ministry staff. Such an approach will be highly cost effective and provide Ontario with a network of computer based systems that will allow users to get the most out of their system through mutually beneficial cooperation with each other and the Ministry in an ongoing program of improvements.

2. INTRODUCTION TO COMPUTERIZED TRAFFIC CONTROL SYSTEMS

2.1 Background

The development of traffic control signal systems for urban streets has paralleled the development and use of the automobile. For their foundation, traffic control systems depend to a great extent on the technology of signalling systems developed for the railroads. Interconnected signal systems had their start in Salt Lake City in 1917, where six intersections were manually controlled in a single system. In 1922, in Houston, Texas, 12 intersections were controlled as a simultaneous system from a central traffic tower. This system was unique in that it used an electric, automatic timer.

Six years later, in 1928, a flexible-progressive pretimed system was introduced. These pretimed systems were quickly accepted, and widespread installation followed until they were common in virtually every city. It could be speculated that their success was the result of (1) their simplicity - almost any electrician could understand them, (2) their reliability - rugged components were used, so that with minimum maintenance, they could be installed and forgotten, and (3) their relatively low cost.

It was recognized, however, that the early pretimed systems had limited flexibility. They could respond to traffic changes only as well as their operator could predict them and preset the systems to change on a time clock basis. But predicting traffic conditions was difficult because of the efforts needed for data collection and the variability of traffic. Timing changes usually were avoided because of the time required to go to each local intersection controller to make the required changes.

Traffic-actuated local controllers using pressure detectors became available during the period 1928-1930. These controllers were a first step toward traffic-actuated control, but were only applicable to isolated intersections.

As a step toward advancing the state-of-the-art of traffic control systems, an analog-computer control system was developed and installed in Denver, Colorado, in 1952. This system attempted to apply some of the concepts of actuated isolated intersection control to signalized networks. Sampling detectors were used to input traffic flow data, and the system attempted to adjust its timing on a demand, rather than time of-day basis. Over 100 of these type systems were installed during the 10 year period from 1952 to 1962.

Like the analog computer, the digital computer became available as a traffic-engineering tool in the 1950's. The first successful application occurred in Toronto in 1959, when a pilot study was undertaken on Eglinton Avenue. The study was successful enough to prove the feasibility of using digital computers to control traffic flow. Before that time, existing automatic-control techniques were not sufficiently advanced to handle Toronto's traffic congestion problems. Following this Toronto study, there developed a steady increase in the application of the computer in traffic control systems. Today over 100 communities in North America are operating digital computer-based traffic control systems.

2.2 Control Concepts

The computer is only the latest tool available to the traffic engineer to try to optimize vehicular traffic movement in urban areas. Coordination of traffic signals, the most effective aid in utilizing available roads to their maximum capacity, may be achieved in many ways using a variety of techniques and equipment.

A number of Ontario municipalities are operating centralized traffic control systems, MTSS being the most widely used. The MTSS system can co-ordinate of an unlimited number of intersections through the transmission of synchronization pulses and split, dial, and offset select commands to inter-connected intersections. Up to 3 dials, 3 offsets and 2 splits and a small number of special functions may be selected from the central console either manually or on a time-of-day basis. Communications is over a multi-pair cable using direct DC or AC signals or over telephone lines using tone telemetry. A number of independant subareas may be controlled, with the subareas being defined by the configuration of the communications network.

MTSS types of systems are available from suppliers today. Although the equipment performing the control and communications functions is up to date, utilizing microprocessor-based control logic and possibly digital communi-cations techniques, the control concepts and capabilities are not substantially improved.

Improvements in traffic control and traffic management may be achieved only by changing the control concept, not the equipment performing the work. Computerized traffic control systems being installed in many large and small cities today provide improved traffic control not because they employ computers as the control element, but rather because computers permit the implementation of control techniques not achievable through the use of non-computer equipment.

The main feature missing from the MTSS type of system is the capability to bring traffic information and equipment performance data back to central. Traffic demand information can be used to select the most appropriate signal timing plan to be implemented. The impact of the signal plan on traffic performance may be monitored and timings adjusted to further improve traffic movement. The concept of controlling traffic in response to measured traffic demand is called traffic-responsive control.

A number of arterial control systems operating in Ontario are in fact traffic responsive in a limited sense. Vehicle detectors placed in the roadway feed traffic volume and density (occupancy) information to the master controller. The master controller then selects the most appropriate preselected signal plan and commands local controllers to change dials, splits and offsets, as required, while maintaining coordination. Arterial masters are limited to controlling one subsystem and thus several such masters are required in a city of medium size. Naturally, central monitoring of equipment or vehicular demand is not possible.

Today's central masters, using minicomputers or microprocessors as the control element improve significantly upon both the MTSS type central masters and the arterial masters while providing the capabilities of both of these earlier systems they may potentially replace.

Computerized traffic control systems (CTCS) have the capabilities to control traffic on a time-of-day, traffic-responsive or manual basis. A large number of subsystems may be controlled independently with subsystem boundaries not being limited by the fixed communications line network. Subsystem boundaries may be changed automatically by time-of-day or manually, by simply typing a few commands at the system console.

Traffic responsive plan selection is achieved through more sophisticated pattern matching algorithms than are available with arterial master controllers. Efficient and effective timing plan transition routines reduce traffic disruption upon plan changes to a minimum.

One CTCS may replace several arterial and several area control systems in a municipality, while providing cost savings in the process. In addition, operational problems are siginificantly reduced by the fact that most of the equipment is concentrated in the traffic control office. A medium-scale CTCS can control up to 250 intersections.

The most significant advantage today's CTCS's have over earlier control systems is the amount of information that may be transmitted to central.

This information includes traffic flow data and equipment status information. This information permits the automatic creation of historical traffic data bases, the continous evaluation of on-street traffic performance and the effective selection of traffic signal plans to best meet existing traffic requirements.

The capability to centrally select and control each display interval at the local intersection is also provided. By entering a number of a simple commands at the master console, the traffic engineer may change the length of any green interval to any desired value and within seconds receive confirmation of the implementation of his newly entered timings. Most systems also permit the central selection and actuation of special functions such as flashing operations, changeable message signs or lane control. Confirmation of the operation is sent to central immediately upon implementation.

The continuous monitoring of both controllers and detectors improve system operation, reliability and maintenance. The daily generation of traffic performance figures as well as a continuous log of malfunctioning components provides the traffic manager with a valuable tool to improve overall traffic operations.

Table 1 summarizes the capabilities of the three types of master controllers available today: on-street masters, central masters of the MTSS type, and computer-based traffic control systems.

2.3 System Components

The major components of a traffic control signal control system are discussed in the following pages. Figure 1 depicts these components and the communications paths between them. In existing conventional systems, the feedback paths, marked with dashed lines, do not exist. Thus, information from the street is not fed back to the central master to provide monitoring and surveillence information and to allow traffic responsive selection of signal timing plans.

2.3.1 Central Facility

The central facility of a traffic control system includes the central master, peripheral devices and communications elements. The central master in all but the largest systems is a mini-computer or a group of interconnected micro-processers. The exact nature of the central processer is of less importance than the characteristics and capabilities of the unit.

Areas of Interest	Function	On-Street local master dial select	Central Master dial select	Central Computer
On-Street Operations	No. of timing plans normally provided	3 cycles 3 offset 3 splits	3 cycles 3 offset 3 splits	Virtually unlimited
	signal plan selected from:	street	central	central
	Options-preemption, special functions, bus priority, etc.	very limited	limited	unlimited
	Signal timing update	street	street	central
Maintain-ability, Reliability	Reliability	good	fair	fair
	Monitoring	no	no	yes
	Automated diagnostics	no	no	possible
Operational Efficiency	Detector Data	no	no	yes
	Reporting	no	no	yes
	Flexibility with subsystem	no	no	yes
Capital Cost	Master	$1,000-$25,000	$15,000-$30,000	$50,000-$150,000
	Local	$100-$500	$500-$1,500	$1500-$2500

TABLE 1. SUMMARY OF THREE TYPES OF MASTER CONTROL SYSTEMS

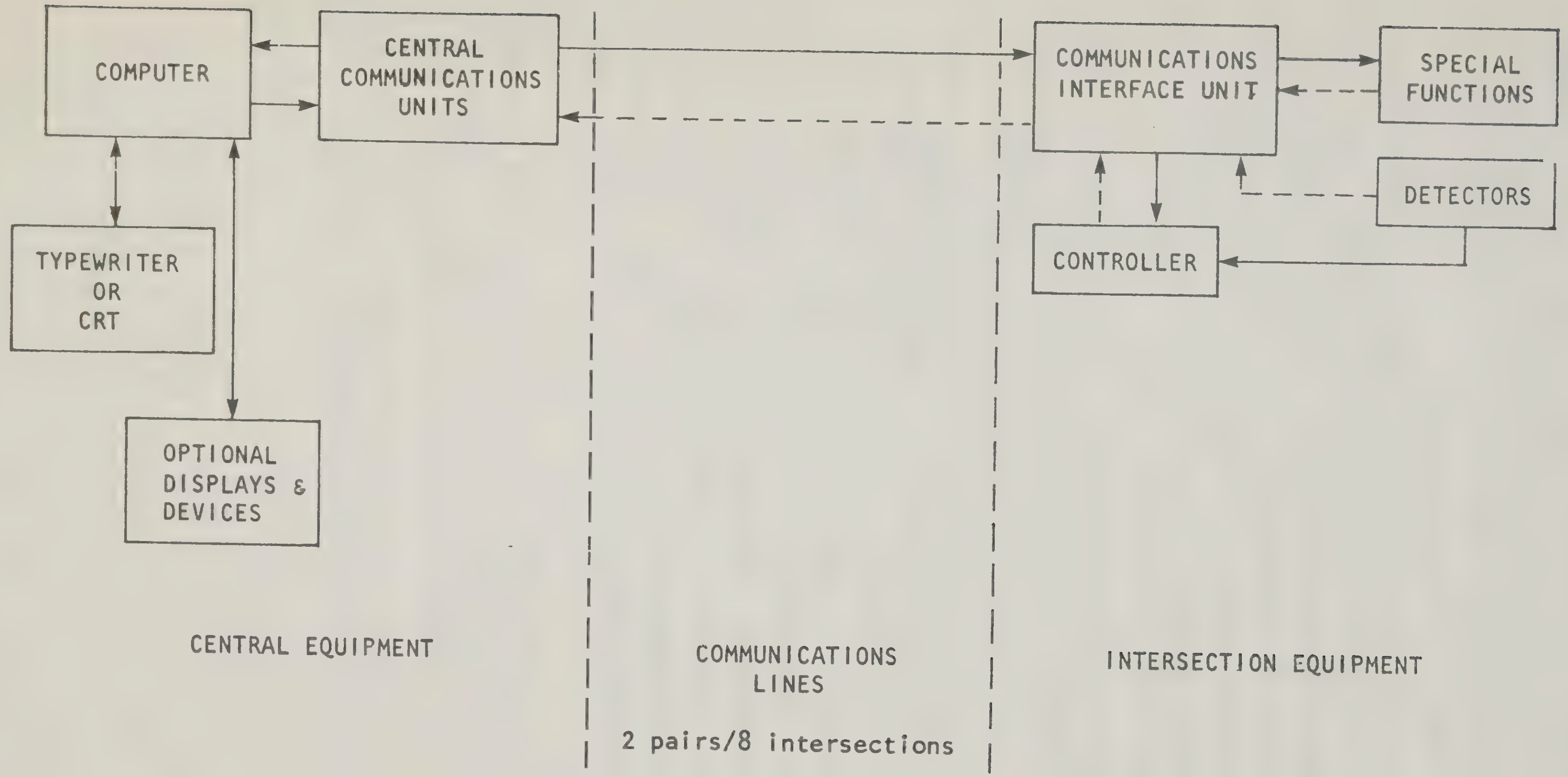

FIGURE 1 Computer System Components

The key concern is that the amount of processing capability be sufficient to meet both the short-term and possible long-term needs of the user. Processer speed and memory expansion capability must be such that the expected size of the system in five to ten years' time can still be accommodated in the machine with little modification. Most available smaller systems are designed to gracefully expand to allow control of approximately 250 intersections.

The user must next decide whether he wishes to use the traffic control computer for purposes other than traffic control, such as data processing or general scientific computing. Computers which provide this added capability are more complex, more costly, less reliable and require greater operator expertise. Users who wish to keep their systems simple should not specify general computing capability in their central processor.

The user must be able to communicate with the computer. This capability may be provided through an operator's console, which can take the form of a CRT terminal or typewriter connected to the computer. Output from the computer may be otained through a printer, or, where higher speeds are required, by a higher speed line printer which can produce several hundred lines of print per minute.

Devices which permit the computer to permanently store large amounts of data are generally required. These devices serve as extensions to the computer's main memory and serve to store timing plans, traffic data as well as the control software for the system. The most common forms of mass storage are tapes, disks and floppy disks. Disks are favoured because of their reliability and speed as well as modest cost.

In addition to producing data on a printer or CRT, most systems have the capability to display more grahically, system or intersection operation. A map of the network under control is often provided, with lights or numeric displays at controlled intersection to indicate anything from measured vehicle speeds to pedestrian calls and green

intervals in force. Some systems offer console displays showing in detail one intersection with all signals and detector status. Displays of this type are useful not only for the operator but also as visible and readily understandable symbols for viewing by the general public. The dual purpose of map disply should be kept in mind.

2.3.2 Local Intersection Control

Presently available computerized traffic control systems are designed to operate with almost any existing local controller. As a minimum, the central computer times all the green intervals of a fixed-time controller. Semi-actuated control is most commonly achieved by issuing "yield" and "force-off" commands to the local actuated controller. More flexible control may be achieved by using so-called "system" controllers. These controllers are designed to operate with particular central systems and allow remote modification of phase sequences and interval lengths.

To allow existing electromechanical or solid state controllers to communicate with the central facility a communications interface unit (CIU) is required. This unit translates the computer's commands into appropriate relay actuations and translates controller and detector signals into digital form for transmission to the central facility. The CIU contains both the communications elements and the logic circuitry to permit coordinated control of the intersection controller by the central. System controllers, containing the communications and logic elements found in CIU's may be used, eliminating the need for any additional intersection hardware.

Solid state fixed-time controllers are also controlled in the fashion described above. With solid state controllers greater phasing flexibility may be achieved as more than one cam is generally selectable.

Two techniques are commonly employed to centrally control pretimed controllers; cam control and dial control. In the cam control method, the local time clock and dial are disconnected by the computer and the electrical path is diverted so that the computer controls a relay which causes the local controller to advance from one timing interval to the next. The computer thus controls each timing interval at each location directly.

With dial control, the computer controls Dial 2 and extends the preset minimum green intervals so that any given cycle length (above a predetermined minimum) and any combination of offsets and splits can be developed. Clearance and all-red intervals are generally not controlled from the computer. If computer control ceases for any reason, Dial 2 is released and Dial 1 automatically reselected. Dial 1 keys are set to provide appropriate stand-by timings. If the computer is shut down deliberately, correct offset relationships between intersections may be established by the computer so that coordinated operation can be maintained for some time even without computer control.

Actuated control may be achieved in two ways. Actuated controllers may be controlled from the central facility by the transmission of "yield" and "force-off" commands. This form of control makes use of the built-in logic of the controller to select the appropriate "next" phase. The yield point defines the minimum interval length while the force-off point defines the maximum time an interval may be in force. Through the use of yield and force-off commands actuated controllers may be used to provide semi-actuated control in a network. If deemed desirable, these controllers may be released from central control to operate as fully-actuated controllers at certain times of the day or upon computer failure or shut down.

A limited form of actuated control may be achieved using fixed-time controllers and some controller modifications. Phase skipping is difficult to implement but may be achieved through the use of special function commands. Most systems offer a number of special function commands. This feature may be used for actuating flashing advanced greens, turning signs on and off or for implementing a limited degree of phase skipping.

System controllers with actuated control capabilities offer the greatest flexibility in intersection control. The controllers contain integral communication equipment, detector preprocessors and remotely alterable memories. As the communications capability is built into these controllers, a separate CIU is not required. Remotely alterable memory allows local controller standby timings, normally set at the intersection to be selected from the central master. Normal, as well as standby timings can in this way be modified without the need to visit the intersection. The drawback of system controllers is their greater cost and limited ability to interface with systems other than the one for which they are designed. Technological and marketing advances should reduce these problems in the future.

2.3.3 Vehicle Detectors

A vital element of the total traffic control system is the surveillance subsystem. The detection system provides all information upon which decisions and evaluations are made. Most applications to date have used inductive loop detectors for vehicle sensing. These detectors are relatively reliable and provide sufficiently accurate information for the analysis techniques in use today.

Magnetometer and radar type units have been tried to a limited extent as vehicle detectors. Closed-circuit television has been used as part of surveillence systems; however television must be considered a special purpose device in most applications; a supplement to some other basic surveillence system.

The output required from system detectors is an accurate representation of the time a vehicle occupies a given zone, and the number of vehicles passing a point in the roadway in a given time. The length of occupancy is used to define travel speed and level of congestion.

One function of the ICU is to process and transmit detector data to central. Rather than transmitting continously the detector signal as it comes from the detector amplifier, the ICU accumulates volume and occupancy information for transmission once or twice per second. This is necessitated by the need to minimize communications line usage. Normally, occupancy accuracy of one part in thirty-one is provided. This is sufficient for most forms of control. Where vehicle speed information is not crucial, occupancy information resolution may be sharply reduced. In either case accurate vehicle counts are sent to central.

Detector data is used for traffic responsive plan selection as well as for the generation of traffic surveillance data for signal plan optimization. Measures of effectiveness may also be derived from this information to permit comparison of the effectiveness of various forms of control and different timing plans. In addition, central monitoring of detectors allows rapid identification of failed detectors. This, along with the monitoring of the functioning of controllers is one of the significant benefits of computerized traffic control.

2.3.4 Communications

The communications network which ties together the central processor and the local intersection equipment is the key and often

the most expensive element in the traffic control system. Because of its importance and high cost great care must be taken to select the most appropriate and cost effective form of communications available.

Although non-wire forms of communications, such as radio, are available, very few actual installations use anything but cable to provide the needed information channel. The options of owned or leased lines must next be considered. It is generally desirable for the operating agency to own its communications network because of the improved service and maintenance that can be achieved. However, unless cable or at least conduit are already available, the cost of installing dedicated lines for traffic control needs is prohibitively expensive. Even amortized over twenty-five years, the cost of installing lines is generally several times greater than the cost of leasing lines of the same capacity.

Problems encountered by users operating over leased telephone lines must be pointed out. These problems may be technical or operational. Technical problems related to noisy or poor-quality lines can generally be overcome through sophisticated error detection schemes. More difficult to deal with are the problems related to poor maintenance, slow response to needs and new installation requirements. It is strongly advised that where phone lines are to be used, early liaison be set up with the local representative of Bell to try to gain cooperation in the planned venture and some assurance of acceptable ongoing support.

To minimize costs, especially of leased lines, multiplexing techniques are employed. Multiplexing means the use of one pair of lines to carry more than one channel of communications. One channel may be thought of as providing the required on/off signal to one relay. Frequency division multiplexing (FDM) creates separate channels over one wire pair by designating a different frequency or tone for each channel. Up to twenty separate channels may be created on a leased voice-grade line. Very common in the past, FDM is not widely used in modern systems because of cost, reliability, and convenience considerations.

Time division multiplexing (TDM) provides distinct channels by allocating time to each channel within each communications interval. The number of channels that may be carried over a given line is limited by the electrical characteristic of the line and the communications equipment used. The number of intersections that may be served by one line depends on the amount of information required per

second per intersection. Typically, eight intersections and up to 32 detectors may be serviced over two pairs of telephone lines. The communications mode is full duplex, TDM, with frequency shift keying (FSK). TDM is especially suited to computer systems as the digital format is readily accepted by digital computers. By full-duplex is meant the simultaneous transmission of information in both directions.

Because of the prime importance of the communications network it must be reiterated that a great deal of attention should be paid to this aspect of any proposed system.

2.3.5 Control Software

Software is the set of program instructions stored in the computer which permit the implementation of desired control and operational strategies. In software is contained all that defines the operation of the computer as a traffic control device.

Some mention should be made of the language in which software is written and the implications of different languages for the user. Commonly, systems are available written in either assembler or in FORTRAN. Assembler programs will generally only work on one particular make of computer, while FORTRAN programs will run on most mini-computers and all larger general purpose computers with possibly some minor modifications. Perhaps more significantly, assembler language programs are substantially more difficult to understand and modify than FORTRAN programs and additions to software are equally more difficult to accomlish. FORTRAN language programs can simplify the exchange of programs between users and makes it possible for non-computer staff to at least understand the software package after some training. A serious effort has been undertaken in the United States by the Federal Highway Administration to develop a standard traffic control software package written in FORTRAN, called UTCS. This package is now available, and is being accepted with mixed enthusiasm by users and suppliers.

A number of traffic control strategies of differing complexity and effectiveness have been tried to date. The most widely used is known as "First-Generation" type. The technique relies on the selection of appropriate traffic control plans from among a set of predefined timings, based on measured traffic levels. Detector volumes and occupancies are combined in some form and matched with patterns stored in

the computer. With each stored pattern is associated a particular set of signal and network timings. New plans may be selected as often as every five minutes but generally at least fifteen minutes must pass before a new plan is introduced. Detector information is constantly accumulated and processed and comparisons with stored patterns made. This is a highly refined and much improved form of the technique employed by traffic responsive arterial master systems commonly used today.

All systems provide for time-of-day selection of timing plans. Time-of-day plans should form the backbone of any central system. They should provide a framework within which traffic responsive plans selection is permitted on a selective basis. Available systems permit more than enough plans to be selected either by time-of-day or in response to traffic conditions.

"Second Generation" control, still in the trial stage, involves the automatic generation of optimized signal settings based on real-time traffic data. Optimum settings may be produced and implemented as often as once every fifteen minutes. In "Third Generation" control, no network timings are generated, rather signal settings are changed on a continuous basis. Much work remains to be done in this area. Both Second and Third Generation control do away with the need to produce signal timing plans by the traffic engineer. Should these techniques prove their effectiveness they will be a significant step in the direction of simple, effective computerized traffic control.

3. BENEFITS OF CENTRALIZED TRAFFIC CONTROL

Computerized traffic control systems benefit both the general public directly, in terms of improved on-street traffic performance, as well as the system operator by improving system flexibility, simplifying maintenance and reducing total operating costs. Improvements thus fall into three categories:

1. Improved traffic performance
2. Improved equipment maintenance
3. Improved Traffic Department operation

3.1 Traffic Performance

The greatest improvement in traffic movement comes about when previously isolated signals are interconnected and operated in a coordinated fashion. A properly-timed coordinated system almost always shows significant improvements over a non-coordinated system. Performance improvements of 30% to 50% are often quoted. These improvements are manifested in higher travel speeds, reduced accidents, reduced congestion and delay, and fewer stops. When translated into dollar terms the benefits accrued often return the capital invested in installing the system in less than one year.

Where signals are already interconnected in a single central system and operating well in a coordiated fashion, direct traffic improvements offered by a traffic responsive central computer may be limited. Nevertheless, computer acquisition has almost always resulted in improved traffic flow for the following reasons:

- the method of offset transition is less disruptive to traffic;
- the traffic responsive control algorithms are more sophisticated;
- sophisticated on-line detector error checking is used to prevent control decisions based on bad data;
- manual intervention is possible to allow the system to adapt to unusual events;
- signal timings are updated more frequently;
- up-to-date date base;

There are also other significant benefits of computerized traffic control which fall outside of what is strictly the control area but which can help justify computer acquisition.

3.2 Maintenance

While efficient traffic movement is the prime concern of system users and operators, maintenance and the cost of system operations are additional concerns of those responsible for operating traffic control systems. It is the operator's responsibility to provide good service at an acceptable cost. The impetus to upgrade an existing system often comes about because of increasing maintenance and operating costs caused by aging equipment. Traffic may be moving in an acceptable manner but the time and cost involved in keeping the system operating may not be acceptable. In some situations, reduced maintenance costs may be an important consideration in justifying computer acquisition.

Two factors help to improve the reliability and reduce the maintenance costs of new equipment. The first is the higher reliability of components manufactured today with solid state and integrated circuit technology. Thus any elements of an older system (controllers, communications, or central) which are replaced by new components will be inherently more reliable. New products often come with self-diagnostic capabilities, where a unit can be automatically tested and a faulty replaceable module located. Equipment repair can become simply a matter of field replacement followed by laboratory repair.

The second cause of improved reliability is the instantaneous availability of complete information on equipment performance, not available with older systems.

This information produces three principal benefits:

1. Failures which would not be reported with older systems are noted and recorded;
2. All failures are reported immediately and therefore immediate remedial action can be taken;
3. The computer can aid in failure diagnosis by indicating the type of failure and the time of occurrence and its duration. This is especially useful for diagnosing intermittent failures.

Because of the information-handling capability of the computer, accurate up-to-date record keeping of failures becomes feasible. Automatic printouts of monthly or yearly failure histories can help identify troublesome components or failure types so that appropriate action may be taken to correct recurrent problems.

These attributes of the newer systems can significantly reduce maintenance costs and make possible the reduction of maintenance staff while improving the reliability of all system components.

3.3 Operations

By operations is meant the management of the total traffic operations effort. This includes not only the day-to-day routine of maintaining the signals and controlling traffic, but also the less frequent requirements to add new signals to the system, to recalculate offsets, to retime controllers, to count traffic, and to monitor system performance.

Many of the previously time-consuming efforts are performed automatically by the computer while controlling signals. The factor that makes more efficient operation possible is the amount of information available to the computer and the flexibility of control the computer can provide. Most computer controlled systems allow individuals without computer training to "converse" with little effort with the computer in a traffic oriented language. Signal timings are modified by simply typing a few commands at the system console. Implementation of these settings is confirmed at the console seconds later. Where a sufficient number of detectors are installed, the impact of the new timings on vehicle speed, occupancy, delay, and stops may be made available.

Detector data fed back from the intersection is stored by the computer in a historical data base file. Detailed printouts of vehicular demand and other traffic parameters, for any period of time, can be produced at a later date. Such information is useful for planning studies and signal timing plan generation. Because the number of manual counts required is reduced, cost savings are also realized.

The ready access to such traffic data offers the system operator the oportunity to provide the public with the highest level of service at great cost efficiency.

3.4 Staffing

It would be theoretically possible to profit from computerized signal control by maintaining the functions of Traffic Control, Maintenance and Operations at their previous levels and using fewer staff members. However, cities do not generally do this. The potential for improved operation is so great that most cities in fact find it cost effective to increase traffic operations staff. This does not imply that computer systems require larger staffs to support them, but that computer systems offer so much potential for traffic improvement that a large percentage of the potential improvement may apear to be wasted unless additional human resources are added.

4. STATUS OF TRAFFIC CONTROL IN ONTARIO MUNICIPALITIES

As part of the MTCS project a questionnaire was circulated to over forty Ontario municipalities in January 1977. Questions covered the areas of local traffic problems, existing equipment, planned puchases, operations and manpower.

The aim of the questionnaire was to determine the status of traffic control in Ontario and to provide information useful for the definition of system requirements. Table 2 (next page) lists the surveyed municipalities along with the number of signals operating therein.

Appendix B contains a sample questionnaire and a list of participating municipalities. Appendix C contains the summaries of responses. The following section contains an analysis of the responses.

4.1 Central Control Systems

Eight municipalities surveyed had centralized traffic control equipment, either MTSS, Selectrol or Monotrol. Some of these systems are operating well, while others are causing problems as the equipment ages. Some components are expensive to replace and difficult to obtain, making system maintenance and expansion difficult.

Table 3 below presents in summary the types of master control systems being operated in Ontario. Comments following the Table provide additional information.

City	System Name	No. of Signals on System	Comments
Kitchener/Waterloo	MTSS	10 directly	1.
	Selectrol	65 driven by MTSS	1.
London	MTSS	46	2.
Chatham	MTSS	8	3.
Oshawa	MTSS	47	4.
St. Catharines	MTSS	33	5.
Guelph	Selectrol	12	6.
Belleville	Monotrol	19	7.
Sault Ste. Marie	Monotrol	41/2 systems	8.
Toronto	Univac	1200	9.
Ottawa	Honeywell 700	300	10.
Hamilton	-	200	11.

Table 3/ Centralized Traffic Control Systems Operating in Ontario.

Municipality	Number of Traffic Signals
Toronto*	1200
Ottawa*	400
Hamilton*	250
Kitchener/Waterloo	153
Windsor	150
London	120
Mississauga	126
Sault Ste Marie	71
Oshawa	78
Thunder Bay	77
St. Catharines	79
Guelph	67
Kingston	66
Peterborough	64
Sudbury	66
Brantford	53
Sarnia	54
Burlington	49
Cambridge	46
Oakville	40
Niagara Falls	46
Cornwall	31
North Bay	33
Belleville	33
Welland	34
Brampton	35
Barrie	29
Chatham	23
Richmond Hill	22
Orillia	21

* Municipalities not surveyed

Table 2/ Ontario municipalities with more than 20 signals. (1977)

1. Kitchener/ Waterloo - MTSS, Selectrol

A Selectrol system was installed in 1956 and upgraded in 1971 to MTSS. The MTSS master is used to select timing plans on a time-of-day basis. The selected plans are passed on to the Selectrol communications system for transmission to the intersections, as the MTSS communications equipment has created many unsolved problems. Communications is over Bell lines. Selectrol is also subject to periodic failure. Lack of equipment for expansion and aging existing equipment has precipitated a need to replace the existing system.

2. London - MTSS

MTSS was installed in mid to late 1960's. Long standing communications problems have recently been ironed out. The system is operating according to specification. Communications is over Bell lines at a yearly cost of $4,000 for 45 pairs of lines.

3. Chatham - MTSS

The system was installed in 1967 and has been operating well since that time. In addition to controlling signals, MTSS also controls illuminated turn prohibition signs. Communications is over Bell lines. Future scope of the system is limited by the nature of the MTSS system.

4. Oshawa - MTSS

The system was installed in 1966. The system is operational but nearing the end of its useful life. Reed relays need replacing and expansion is difficult because of equipment shortages. Upgrading or replacement will be required in the very near future. Communications is over leased Bell lines which cost $7000 per year for 47 pairs of lines.

5. St. Catharines - MTSS

No information available

6. Guelph - Selectrol

System is no longer in operation.

7. Belleville - Monotrol

The system was installed in 1971 and is operating satisfactorily.

8. Sault Ste. Marie - Monotrol

The first system was installed in 1962, the second in 1975. One system operates the 25 CBD signals, the second 16 arterial signals, both giving 2 dial, 3 offset operation. Five fire lane preemption routes are controlled by Monotrol.

Communications is over leased Bell lines, one pair per intersection. The system is not responsive to traffic variations. Traffic responsive system will be considered to replace the existing system within the next few years.

9. Toronto - Univac

Toronto had the first digital computer controlled traffic control system in the world. Installed in the early 1960's it now controls over 1200 intersections. The system is now being redesigned to permit necessary expansion and to replace aging components. Communications is over leased Bell lines using tones. Four pair of lines go to each intersection. The computer sends cam-advance commands to each intersection with 1/4 second resolution. Up to ten detectors per intersection may be monitored.

10. Ottawa/Hull - Honeywell

Ottawa has recently completed the installation of a computer-controlled traffic control system. At central are dual Honeywell H716 computers, using the OS/700 Executive. Communications is digital over leased Bell lines with up to 8 controllers on two pairs of lines. Up to 32 detectors may be monitored per 8 intersection. The computer sends advance commands to the intersections with 1/2 second resolution. Traffic plans are selected from a large number of stored plans based on existing traffic conditions. The system is expandable to over 400 intersections and 1000 detectors.

11. Hamilton

Hamilton is presently operating two locally designed central master control systems installed in 1960. Approximately 200 of the city's 250 intersections are connected to the master controller. Communications is over city-owned seven-conductor cable with intersections connected in parallel or in a multi-drop fashion. Controllers have 3 dials with one offset per dial. Six functions may be controlled from central through direct AC activations of relays at the controller. The acquisition of a new computer-controlled system, given consideration in 1977, has been delayed.

As indicated in Table 3 a number of municipalities are experiencing operational and maintenance problems with their central master control system. Adequate replacement systems will have to be found very shortly if a deterioration in traffic performance in these municipalities is to be avoided. Table 9 is a summary of planned system acquisition by municipalities as stated in the fall of 1978. It is anticipated that a number of the cities sited under "other" will eventually end up with computer-based systems.

4.2 Arterial Masters and Local Controllers

Twenty-two interconnected arterial sytems are operated by local masters. These systems range from single-dial interconnected to sophisticated traffic responsive volume/density masters.

Table 4 below shows the types of controllers operated by the municipalities surveyed. Approximately half of this total is the CGE Type F. MTC signals within the municipal or regional jurisdiction are also included.

Controller	Number	Percent of Total	Actuated	Percent Actuated
MTC	108	5.9%	35	32%
Electro-Mechanical	1167	67.5%	163	14%
Solid State	562	32.5%	183	32.6%
Total	1837	100%	381	20.7%

Table 4. Controllers Operating in Ontario Municipalities

Municipal and Regional traffic offices were planning to install approximately 110 signals in 1978. A breakdown of controller types is shown below in Table 5.

Electro-Mechanical		Solid State	
Fixed time	Actuated	Fixed time	Actuated
43	14	0	54

Table 5. 1977 Planned Equipment Purchases

4.3 Traffic Problems

A majority of Ontario municiaplities is experiencing traffic problems within their jurisdiction. Table 6 presents a summary of the responses received.

Congestion Cause	Number of Municipalities	Percent
Industrial	28	76%
Commercial	11	30%
Recreational	11	30%
Railroad	10	27%

Table 6. Sources of Traffic Congestion

Some municpalities experience more than one source of congestion. Table 7 below provides this summary.

No. of Congestion Sources	No. of Municipalities	Percent
None	3	8%
one	13	35%
two	17	46%
more	4	11%

Table 7. Preponderance of Congestion

Municipal traffic departments were asked to rate the performance of their existing traffic control system. The answers are summarized below in Table 8.

Traffic Control System	No. Of Municipalities	Percent
Good	5	13%
Adequate	18	49%
Needs Improvement	14	38%

Table 8. Traffic System Performance

Analysis of responses received indicates that congestion problems are experienced in a majority of Ontario municipalities. In nearly 40% of municipalities improvements to the traffic control system are required.

At the present time only three municipalities have indicated an intention to preceed with the purchase and installation of improved centralized control systems. This leaves more than ten municipalities with inadequate traffic control systems. As the cost of centralized traffic control continues to drop and effective systems that meet Ontario requirements are demonstrated, municipalities not yet ready or able to undertake system improvements may be encouraged to upgrade their existing system. Experience gained with the installation of the initial systems during Phase II of the MTCS Project will help in this process.

Need	Computerized System	Other Systems
Immediate	- Brantford - Kitchener/Waterloo - Durham (Oshawa)	- Cornwall - Orillia - Peel - Thunder Bay - North Bay - St. Catharines
2-5 Years	- London - Sault Ste. Marie	- Brampton - Guelph - Oakville - Sudbury
5-10 Years	- Guelph	- Windsor - Burlington - Timmins

Table 9/ Planned Traffic Control System Acquisitions by Ontario Municipalities

4.4 Operations

One section of the questionnaire dealt with municipal traffic control staff and signal operations budget.

Eighteen jurisdictions reported having at least one traffic engineer with traffic engineering responsibilities on staff. A large number of other professionals with traffic engineerig experience have primarily administrative responsibilities in traffic and transportation departments. There are thirty-three full-time and five part-time traffic technicians in traffic departments.

The average operating budget was found to be $1750/signal/year in 1975. The total amount spent on signal installation and maintenance was $3,066,000* in 1975 and $3,411,000* in 1976 with a subsidy of $1,128,000 for 1975 coming from MTC.

The replies to the questionnaires provided material for voluminous statistical analysis of dubious interest. One overriding concern was however voiced in the many interviews with respondents. This was the clear indication that budgets were tight, staff limited and chances for increased staffing slight. The number one requirement for any system therefore has to be simple operation manageable by traffic engineering personnel. Systems have to be tailored to staff capabilities, rather than the other way around. This concern was noted and kept in mind during system requirement preparation and system review.

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* Amount shown is for municipalities surveyed through the MTCS questionnaire.

5. TRAFFIC CONTROL REQUIREMENTS FOR ONTARIO MUNICIPALITIES

The following section presents a list of system requirements with a brief description of each. The requirements are grouped into classes of: Essential, Desirable and Optional. These requirements were developed with a knowledge of the features which are available in current off-the-shelf systems. If bid documents were prepared which specified the following requirements, a number of manufacturers would be in a position to bid their standard systems with few, if any, modifications.

These requirements were developed by MTCS project staff based on the analysis of responses received to the MTCS questionnaire and following discussions with likely system users and consultants. The requirements are summarized below.

5.1 Summary of System Requirements

A. Essential Requirements

1. Adequate number of control areas and timing plans
2. State-of-the-art offset transition
3. Operator manual override
4. Traffic-responsive subarea plan changes
5. Time-of-day override capability of traffic-responsive plan changes
6. Effective on-line error checking of all detectors
7. Centralized special function capability
8. Modular expansibility
9. Proven system performance
10. Traffic engineering language
11. 24-hour unattended operation
12. Automatic restart procedure
13. Central input of fixed-time timing parameters
14. Ability to interface conveniently with existing control equipment
15. Equipment status monitoring and daily summary reports of equipment malfunctions
16. Volume and occupancy reports, daily summaries and current status reports.
17. Automatic historical data base generation.

18. Adequate reliability of the central master in an office environment.
19. Convenient treatment of flashing advance green.

B. Desirable Features

1. Central control of semi and fully-actuated intersections
2. Critical intersection control
3. Variable amber and all-red intervals
4. Fail soft and coordinated stand-by mode
5. Continuing operation upon disk failure

C. Optional Requirements

1. Emergency vehicle priority routing
2. Data processing capability
3. Remote alarm
4. Display map
5. Remote terminal
6. Stand-by power source

5.2 Essential Requirements

1. Adequate number of control areas and signal timing plans

Traffic engineering departments normally are limited by manpower to a certain amount of analysis. This manpower limitation normally means that five or six timing plans at the most will be implemented and that control areas which change their timing plans independantly are kept to a minimum number. Most cities with three-dial interconnected fixed-time equipment with multiple-offset and multiple-split capability do not take full advantage of the present capabilities of their equipment. Computers can provide for a number of plans and control areas much beyond that of electro-mechanical multi-dial equipment. All existing computer systems exceed the requirements of any normal municipality for the number of control areas and timing plans.

2. State-of-the-art offset transition

All computer systems have offset transition techniques which are significant improvements over the offset transition capabilities of other systems. Although slight differences exist between systems, they may be considered as essentially equal.

3. Operator manual override

In most systems, the operator has control of all individual intersection timing parameters and all control area plan changes. In systems where actuated intersections are controlled, the operator cannot change timing parameters such as initial interval and extension from the central location unless a system controller is being used. The operator has a choice of fixed-time or actuated control with some systems and can determine the background cycle length under which the actuated controller operates. This flexibility normally exceeds the needs of the traffic department.

4. Traffic-responsive plan changes

All systems offer some method of traffic-responsive plan selection by means of a pattern recognition algorithms. Differences exist in the exact details of the logic, however, little work has been done to indicate the advantages of one algorithm relative to another.

5. Time-of-day override capability of traffic-responsive plan change

In order for traffic responsive control to be effective the frequency of plan changes must be limited to avoid frequent disruptions caused by the changes themselves. Time-of-day override ensures that certain required traffic plans are implemented and maintained during predictable traffic conditions such as rush hours. Outside these perids, traffic responsive selection is allowed to function but with a minimum effective duration for each plan.

6. Effective on-line detector error checking

Detectors are the most sensitive components of a computerized traffic control system. If the detector information is faulty, poor control decisions will be made, both by the real-time elements of the system and by the analyst. Good detector error checking can guarantee that bad data will be ignored and can point out immediately to maintenance personnel when corrective measures must be taken.

7. Centralized special function capability

The implementation of special features such as flashing amber, all red operation, reversible lanes, variable message signs, and variable phasing are handled by what is called a special function capability. These special functions can be implemented on the basis of time-of-day, on the basis of traffic volumes, or by a combination of both. The special function capability allows the computer to control any action which is normally

controlled by a local time clock without the disadvantages associated with time-clock operation such as the need to reset the clock after power failure, the requirement to change the clock with the introduction of daylight saving time, and the general imprecision of most electromechanical timers. Special functions can also be introduced as a function of traffic volumes as part of a traffic-responsive plan change, and on the basis of individual detector actuations (e.g. special phasing based on pedestrian or vehicle actuation). Centralized special function capability is also valuable in that the computer normally monitors the action taken following the special function command to verify that the command was properly received and implemented.

8. Modular expansibility

All systems can be considered to be modularly expansible, however, there are differences in the interpretation of the term based on which modules can be expanded and the nature of these modules. It is possible to modularly expand some systems in order to accommodate more intersections or additional functions by adding additional memory modules. Other systems are expanded by adding additional central processors as well as additional memory, CPU and other central equipment. Some systems are modularly expansible in both ways such that, up to a certain point, additional requirements can be met by adding additional memory modules, and after this point an additional processing unit must be added. The only cost associated with expansion in the cost of providing the local communications interface unit at the intersection and the communications line hook-up.

9. Proven system performance

Based on past performance any newly introduced system experiences a considerable period of debugging, development and unsatisfactory performance. In order to try to ensure that contracted schedules and functional specifications can be met with some assurance only systems that have successfully demonstrated satisfactory field operation will be prequalified to submit bids.

10. Traffic Engineering Language

Today all systems are equipped with a user oriented, conversational communication language which facilitates the use of the system by non data processing personnel.

11. 24-hour unattended operation

All systems today are designed for convenient 24-hour-a-day unattended operation. This feature does not indicate that the equipment will operate without failure for long periods of time without breakdown, but rather is more related to a system design philosophy which dictates that the system will not require regular operator supervision. Today all systems are designed with this philosophy in mind, although in certain applications the system is used so intensively by the municipality that this is not the impression given.

12. Automatic restart procedure

Today all systems restart automatically after a power failure. A battery operated clock keeps track of correct time during power failures. For short power failures of the order of a second or so, the computer will behave in a manner similar to electromechanical equipment, essentially carrying on from where it was. For longer power failures, the restart procedure may involve returning control to the local controller and picking up all signals again.

13. Central input of fixed-time timing parameters

All systems under consideration control either the cam shaft or the dial of the local controller directly so as to give the computer complete control over the length of all, or the most important intervals at the intersection. Offsets, splits, and cycle lengths are implemented by the computer and therefore in order to modify these parameters an entry into the computer is made from the central location and no field trip is necessary.

14. Ability to interface conventiently with existing control equipment

All manufacturers have developed or are prepared to develop a modification kit or interface unit which allows their computer to control existing controllers.

15. Equipment status monitoring and daily summary reports of equipment malfunctions

Although details vary among systems, all systems monitor equipment operation and are capable of pointing out controller malfunctions. Some systems provide written reports of malfunctions only on request and only for a specific time period. These are called status report. Other systems automatically provide a daily summary of all malfunctions detected. The ability

to detect all malfunctions particularly in the detector area varies from system to system. These reports are a useful aid in problem diagnosis, provide for speedier repair of problems, and guarantee that malfunctions do not go undetected. If a daily summary report of equipment malfunctions is not provided, this information must be extracted from status reports or the computer console log. This approach is considered inconsistent with the philosophy of an easy-to-use system.

16. Volume and occupancy reports, daily summaries and current status reports

Accurate volume and occupancy data can provide valuable information to the traffic analyst to assist him in pinpointing and solving traffic problems. It is consistent with the overall system philosphy being developed for MTCS that this data should be available in a ready-to-use, easily-read format.

17. Automatic historical data base generation

It is essential that the traffic engineer have access to historical data. This access should be easy, the data should be reliable and the collection and validity checks on the data should not require any involvement from the traffic engineer.

18. Adequate reliability of the central master in an office environment

Central control equipment must be able to operate with acceptable reliability in an office atmosphere. No special humidity or temperature limitations should be imposed by the equipment.

19. Convenient treatment of flashing advance green

The use of flashing advanced and delayed green phases is unique to Ontario. The implementation, deletion or reversing of directions of flashing greens is considered to be an essential feature. This is normally accommodated by the special function capability of the central computer. However, not all systems allow this to be done in a convenient manner.

5.3 Desirable Features

1. Central control of semi and fully-actuated intersections

If semi and fully-actuated control is required, there can be considerable economies in providing these features through the central computer. In addition, the central computer control allows for changes to all semi and fully-actuated control parameters without street modification.

2. Critical intersection control

By critical intersection control is meant the varying of the split at an intersection on a cycle by-cycle basis within a network of signals. This mode is considered superior to the use of semi and fully-actuated control within an overall grid system.

3. Variable amber and all-red intervals

Although little work has been done on the subject, the provision of different length amber and all-red periods during periods of time when traction is poor, e.g. during and after snow storms, would appear to provide some potential for improved safety. Several systems provide this capability as a standard feature and only a few do not.

4. Fail soft and coordinated standby mode

In the event of computer or communications failure, the system must return to local control in a way that is 1) safe, 2) non catastrophic in terms of traffic control and 3) provide the equivalent of a single dial coordinated standby control if communication to the central location is maintained.

5. Continuing Operation Upon Disk Failure

Most systems require some form of on-line data storage for system operations. Some systems require a disk only for traffic data storage. Because of the relatively low reliability of disks it is advantageous to have a system that does not rely on the disk for traffic control operations.

5.4 Optional Requirements

1. Emergency vehicle priority routing

Emergency vehicle priority routing can be provided through either fixed time or preemptive logic. The fixed-time logic involves the use of a so-called moving green window whereby a period of several seconds of

progressive green movement is provided along a particular route which the fire vehicles is expected to take, at a speed which it is expected to achieve. The preemptive type of emergency vehicle routing allows the fire vehicle itself to preempt each signal through electronic means. Little reliable evidence exists of the value of any form of emergency routing. Careful study of this option is required.

2. Data processing capability

The central computer can be used for certain useful data processing application such as timing optimization, parking and sign inventories, accidents records, etc. The data processing can be accomplished either in background mode during traffic control periods or traffic control can be terminated and the entire machine devoted to data processing applications. The difficulty of the second option is that this requires the data processing to be done outside of normal business hours. The first option increases the complexity and cost of the computer.

3. Remote alarm

During periods of unattended operation, it is desirable that an alarm be provided to some work post that is staffed 24 hours a day. If this work post is not in the same building as the computer or at a location where the normal alarm of the computer is not audiable, it becomes desirable to provide an alarm at a remote location so that approriate action can be taken.

4. Display Map

The value of a display map has been questioned by some traffic engineers. Display maps can be relatively simple or quite elaborate in terms of their capabilities. Because of the public relations impact of a display map, some kind of map is almost always provided with a computerized signal system.

5. Remote Terminal

Terminals to provide input and output to the computer at remote locations are useful options under circumstances where the traffic department may be housed in two different buildings or where a single computer system is being used to control signals in more than one jurisdiction. It is even possible to access the computer from an intersection under computer control to enable the technician in the field to observe the operation of the signals following input changes.

6. Standby power sources

In large municipalities where power to different areas of the city is provided from different sub-stations it is possible for power to fail at the central facility while remaining in other parts of the city. Under these conditions it is often desirable to provide a backup power source for the central computer. This capability can be provided in a number of ways.

6. SURVEY OF AVAILABLE COMPUTERIZED TRAFFIC CONTROL SYSTEMS

Information for the survey of available systems was obtained from a number of different sources. Thirteen suppliers listed below were contacted and asked to provide information; however, not all responded to our request.

- Automatic Signal Division of LFE Corporation
- Computer Systems Engineering (CSE)
- Safetran (TDS and Singer)
- Multisonics
- Eagle Signal
- Computran Systems Corporation
- Honeywell
- Philips Traffic Systems
- Gammatronix
- Siemens
- Sperry Systems
- Econolite

After evaluation of the information supplied by the various firms was completed, a followup questionnaire was prepared and sent to the following companies:

- Automatic Signal Division of LFE Corporation
- Computer System Engineering
- Safetrans
- Multisonics
- Eagle Signal
- Computran Systems Corporation
- Honeywell
- Sperry Systems
- Econolite

Other documents were used in the evaluation, such as proposals to a number of Canadian and U.S. cities, and systems descriptions obtained from a variety of other sources. Numerous telephone and personal contacts were also made.

It was not possible to give a description of the systems offered by Sperry Systems, Gammatronix or Philips because adequate information was not available.

Systems are no longer offered in North America by Econolite and therefore they were excluded from the survey. Siemens has a corporate arrangement with Honeywell and do not offer systems independently in North America.

6.1 Comparative Evaluation of Available Systems

Early in the MTCS project it was proposed that available "off-the-shelf" computerized traffic control systems be compared as to the essential, desirable and optional characteristics mentioned in Chapter 5. However, a number of difficulties in doing this comparison soon became obvious.

Firstly, all the systems had all or almost all of the characteristics mentioned above. Secondly, the details of certain characteristics differed (e.g. detector error checking) and it was not always easy to say that one method was superior to another, especially since the evaluation was not being done for any particular city. Thirdly, most of the manufacturers who did not have all of the essential and desirable characteristics would be willing to provide those that were missing. Fourthly, documentation from the various suppliers varied in both quantity and quality so that as a result, the reviewers knew more about some systems than others. Fifthly, responses to questions asked by MTCS project staff were answered more openly and in greater detail by some suppliers, leading again to a varying confidence in the information gathered. And finally, since the evaluation was being conducted without a particular city in mind, it became difficult to state with confidence that those systems which were more elegant than others would be better for all potential end users.

The consensus of the reviewers was that, potentially at least, any of the systems studied could be the most cost-effective in at least some Ontario cities if the bid price was attractive.

This led the reviewers to describe the various systems offered in terms of:

1. Equipment normally supplied,
2. Unique features,
3. The essential, desirable or optional features which are not offered off-the-shelf.

The descriptions are based on the latest information available to the MTCS project staff but, as mentioned earlier, could occasionally be in error because of inadequate documentation, or a misunderstanding by suppliers of questions asked or a misinterpretation of answers.

Table 10 shows a description of seven available off-the-shelf systems for which adequate information was available. It shows the manufacturing and systems competence of each organization and the extent to which each of the systems meets the essential, desirable and optional features which are described in Chapter 5. It is interesting to note that all systems claim to provide the majority of the essential desirable and optional features.

Table 11 shows a tabular comparison of costs for various elements of a computerized control system. Estimates were provided by manufacturers but the Table does not identify the cost of various systems. The last column in the Table indicates a typical cost for each of the various elements. It should be underlined that in some cases, additional costs for detector installation and preparation of intersections for telephone or other communication may be required in addition to these costs. These costs are quoted in U.S. dollars and do not include customs duty. The addition of 1/4 to 1/3 to the prices shown would be necessary to give equivalent costs in Canadian dollars in Canada.

6.2 Detailed system Descriptions

Extensive well-organized documentation was provided by Eagle Signal and Honeywell. These two systems are described below. Comtrac II is one of the simpler, while Honeywell is one of the more sophisticated, of the available sytems examined.

Eagle COMTRAC II

1. Adequate number of sub-areas and timings plans.

This system can accomodate up to 15 different sub-areas which are called signal groups. Seven timing plans are available of which five may be considered usable. Each of these plans contains a single cycle length, 3 offsets and 3 splits which are independent of each other in the manner of the more familiar electro-mechanical or P.R. type electronic equipment. This means of separating splits and offsets from one to another is related to the traffic responsive subplan changing mechanism described later on.

System	Honeywell 6000	Computran Sys. Corp.	Eagle Comtrac II	Multisonics System 220	Safetran (TDS)	Computer Sys. Engin.	LFE 5000
Manufactures Own Computer Equipment	Yes	No. Uses Interdata or Mod Comp	No. Uses Data General Nova	Yes (Microprocessor) Uses Intel8080A CPU Microprocessors in groups	No. Uses Data General Nova	No. Uses Mod Comp	No. Uses DEC PDP/11
Manufactures Controllers A) System B) Non System	 Yes Yes	 No No	 No Yes	 Yes Yes	 Yes Yes	 No No	 Yes Yes
Manufactures Communication Equipment	Yes	No uses TDS or Winkomatic	Yes	Yes	Yes	CSE Design Manuf. under licence	No
Undertakes Major Systems Work	Yes	Yes	No	No	No	Yes	No
Number of Systems Installed and Awarded	19	Several	11	50	3	7	
Essential Features Not Provided		Small systems have no historical data base.	Does not provide daily equipment summaries for smaller systems.	Interface with electro-mechanical controllers not demonstrated.		Cannot vary amber and all red.	No historical data base on small systems.
Desirable Features Not Provided		Small systems cannot vary the length of amber and all red.	Does not have historical data base capability for smaller systems.				Only certain controllers can vary amber and all red (dial dwell).
Optional Features Not Provided		On line data processing not possible with small systems.	Cannot vary amber and all red.	Data processing not possible.			Data processing not possible on smaller systems.
Unique Features		Off line signal optimization package hooked up to computer data base.	Cableless interconnect for standby 16 intersections per channel.	Standby by storing last plan for both controllers and RIU 8 bit words 4 intersections per channel			Cableless interconnection equipment available for standby control.

TABLE 10. AVAILABLE SYSTEMS DESCRIPTION SUMMARY

System	A	B	C	D	E	F	G	Typical
Central Computer	$124,000	$130.000	$125,000	$100,000	$100,000-$250,000	$60,000-$125,000	$100,000	$125,000
Intersection Communications Equipment	$3,500 (installed)	--	$650-$1,750	$1,800	$1,500	$700-1,100	$1,000	$2,000 non system
Modification Kits	$500 Included Above	--	Included Above	Included Above	Included Above	$500	Included Above	$500 or included above
Detector Preprocessor	Included Above	--	$150-$300	Included Above	Included Above	Included Above	Included Above	Included above
Solid State Fixed Time Controller	$2,500	$3,000 -$4,200	$1,600-$2,800	--	--	$1,000	--	$2,500
4 Phase Actuated Controller	$3,000 -$4,000	$3,500 $4,600	$3,000 $4,000	$3,000	--	$1,600	--	$3,500
Software and Systems Engineering	$3,000 -$30,000	?	?	Variable	$0-several hundred thousand	Variable	$50,000	$50,000

TABLE 11. SUMMARY OF AVAILABLE SYSTEM COMPONENT COSTS

2. State-of-the-art offset transition.

The transition algorithm evaluates the number of cycles required to reach a new offset by either lengthening or shortening the cycle length and choses the shortest path. It is a system constraint that each signal must re-synchronize itself in a maximum of 5 cycles. Cycle length may be increased by 17%. This system uses dial dwell as the control technique. If hardware proves to be a constraint in shortening the cycle length so that the inter-section cannot re-coordinate within 5 cycles, then the cycle length is increased in order to arrive at the new offset.

3. Traffic responsive subarea plan changes.

For each subarea of signal group smooth average volume and smooth average occupancy is calculated for a number of detectors. These detectors are divided into groups for inbound, outbound and cross-street traffic. A basic plan or cycle length in chosen based on the highest volume plus weighted occupancy figure for any inbound, outbound or cross-street detector. An offset pattern, which within one plan is limited to a choice of three, is chosen from a comparison of inbound versus outbound flow levels. The split can be selected in two different ways. Each split can be tied to a particular offset so that the choice of offset determines the choice of split or a separate split pattern can be chosen based on the greater of inbound and outbound movements compared to cross-street movement.

4. On-line detector error checking

Test are provided for detector oscillation, constant presence, or lack of count.

5. Centralized special function capability.

No details available.

6. Modularly expansible.

For the COMTRAC II system, 32 K memory is the maximum available and is suitable for controlling up to 100 signals and 100 detectors. A recipe book approach to system design has been adopted by this manufacturer such that a number of optional features are available for system software. The memory requirements of each option are known and the system user can choose the option which he prefers, but must do so, so that the total requirement does not go beyond 32 K.

7. Automatic equipment status reports

A total of 8 separate reports on equipment status are available by time-of-day command or by director operator command.

8. Automatic traffic volume and occupancy reports.

Vehicle counts at 5, 10 or 15 minute intervals are available by operator or time-of-day commands.

9. Automatic historical data base

In its off-the-shelf form the system does not provide a historical data base.

10. Fail soft control

Since this system uses dial dwell, the effect of computer or communications failure can never be dangerous. A back-up synchronization pulse is provided from the central facility in the event of computer failure. In the event of communications system failure, some misalignment of signals on the street could be anticipated.

11. Computer implemented full and semi-actuation.

Although the manufacturer claims to provide this feature no details were given.

12. Critical intersection control

Although the manufacturer claims to provide this feature, no details were given.

13. Direct cam control.

This manufacturer uses dial dwell.

14. Automatic traffic evaluation

In its off-the-shelf form, this system cannot undertake the calculation of measures of effectiveness such as stops and delay.

15. Emergency vehicle priority routing

No special software is provided for this feature but the equipment is capable of monitoring external preempts.

16. Off-line or background computing capability.
This system is capable of doing data processing in the off-line mode only.

17. Display map.
A large wall type display map is available but details of its operation were not provided.

18. Remote terminal
A maximum of 3 terminals can be connected to this system.

<u>HONEYWELL</u>

1. Adequate number of subareas and timings plans.
This system can be divided into 64 subareas. Each intersection can have 30 seperate timing plans. Unlike the previous system, a timing plan consists of any unique combination of cycle, split and offset.

2. State-of-the-art offset transition
This system uses the shortest path method described earlier. If the use of a shorter cycle length during offset transition results in a long re-synchronization time because system input parameters for minimum green time are violated then a longer cycle length is adopted.

3. Traffic responsive subarea plan changes.
A matrix of timing plans is developed for each subarea. A row in the matrix is selected based on a combination of smoothed volume and smoothed weighted occupancy. A column within the matrix is chosen on the basis of the speed calculated for the subarea. The timing plan at the intersection of the row and the column chosen is the one implemented.

4. On-line detector area checking
5 Detector reliability checks are performed. Comparison of the current 15 minute detecter count to that found in the historical volume table is made, see 9 below. In addition, each count is verified against a global undercount and overcount parameter. Checks on minimum and maximum pulse lengths are undertaken. A fifth test involving the number of changes of state per unit time is performed to detect communications failures.

5. Centralized special function capability.
Special functions are timing plan related, therefore the choice of a timing plan by time of day, operator control, or traffic responsive control will result in the implementation of any combination of a maximum of six special functions.

6. Modularly expansible
A single CPU of the Honeywell Level 6 computer is adequate for up to 250 signals. Memory is available in modules from a minimum of 32 K up to a million words.

7. Automatic equipment status reports
Controller failure reports and intersection status reports are available on request or may be scheduled. These reports are available either to indicate the current situation or a summary over a longer period.

8. Automatic traffic volume and occupancy reports.
Both status and summary reports are available by detector and by subarea which indicate total volume and average occupancy.

9. Automatic historical data base.
Two historical data bases are kept. One is a continously updated table giving typical volumes by 15 minute period for each day of the week for all detectors in the system. This table is used in detector reliability checking to record quantities that may be requested for either a volume/occupancy or measure of effectiveness report. Raw volume, raw occupancies, smooth volumes, smooth occupancy are recorded in one second intervals. Stops, delay, demand, and congestion are recorded at the end of each controller cycle.

10. Fail soft control
Because this system uses camshaft rather than dial control, upon either computer or communication system failure, the stand by dial and controller cam shaft can be potentially out of synchronization. This can lead to situations that while not overly dangerous, are less secure than the situation encountered under dial dwell.

Stand-by control can be provided in a number of different manners. The most common is to provide a stand-by dial whose offset position can be controlled and is monitored by the computer. The computer therefore has control over the offset on the standby dial and when a termination occurs the controllers are kept in synchronization by the 60 cycle line voltage. One cycle length and 3 offsets are normally available.

11. Computer implemented full and semi-actuation.
This system provides full and semi-actuation from central in a manner similar to that of electro-mechanical and solid sate isolated controllers.

12. Critical intersection control
Subject to minimum pedestrian constraints, the available green time is proportioned among the various phases according to the critical volume and occupancy for each phase relative to the sum of the critical volumes and occupancies for all phases.

13. Direct cam control
Although this system normally uses direct cam control, it is also capable of dial dwell control.

14. Automatic traffic evaluation
This system provides queue length, number of stops, delay, demand, and congestion for each detector in the system on a cycle-by-cycle basis.

15. Emergency vehicle priority routing
In addition to accepting preemptive type emergency vehicle routing, this system provides a fixed-time emergency vehicle priority by which a "moving green window" is provide for emergency vehicles along pre-determined routes upon request.

16. Off-line or background computing capability
This system can accomplish both off-line and background data processing.

17. Display map

A large wall-type map is available with this system. It is capable of displaying 16 different quantities related to equipment, traffic movements and measure of effectiveness.

18. Remote terminal

This system can accommodate at least three terminals.

7. SYSTEM PROCUREMENT AND INSTALLATION

The following describes a process for acquiring a computerized traffic signal control system. Three key concepts are involved in this process:

- The use of functional specifications
- A two-step bid process
- A prime contractor

1. Functional Specification

As indicated earlier a number of adequate off-the-shelf systems are available. However these systems vary in certain design details. The use of functional specifications allows the municipality to define the requirements of the system it wishes to acquire in functional form, allowing bidders to suggest design details as they see fit. In addition to specifications, construction plans may be required to complete the tender documents. Plan requirements are discussed in Section 7.3.

2. Two step bid process

The first proposal sumitted by prospective bidders is an uncosted technical proposal. This allows the municipality to determine which design details are acceptable and which are not, without disqualifying bidders. Bidders later submit a modified technical proposal with costs. This process helps to ensure that the lowest priced bid meets the requirements of the specifications.

3. Prime contractor

The contract is awarded to a single organization which is responsible for the final performance of the system as a whole. This eliminates the need for the municipality to identify and at times prove who is responsible when problems are encountered. The prime contractor is responsible for the work of all subcontractors.

Early in the process of system acquisition, a consultant may be contracted to assist the municipality in developing specifications. After contract award, the role of the consultant usually diminishes and contact between the supplier and the municipality increases. In small cities where in-house resources may be limited, consultant assistance may be required during implementation.

This approach to computer system acquisition in one form or another has become the most common one in North America. This process attempts to define minimum system requirements in functional form, leaving design details to potential system suppliers.

Further alternative approaches which should be mentioned are direct negotiations with suppliers and the total systems management or entrepreneurial approach where the municipality's consultant takes a larger role in the design of the system. As rule, system components are supplied by several different contractors.

Computerized traffic signal control systems may be acquired in a variety of different ways. Depending on the circumstances, the process may be short, simple and highly subjective or longer, with considerably more qualitative justification.

Normal procurement would involve the following seven steps

1. Council approval and funding committment
2. Selection of system requirements
3. Preparation of Tender Documents
4. Evaluation of technical proposals, costed bids, contract award
5. System implementation and system acceptance

As part of the MTCS Project, MTC staff and the Project System Consultant will assume responsibility for the completion of Steps 2 to 5 with the assistance of each municipality participating in the Project.

7.1 Council Approval and Funding Commitment

A comprehensive report to council to justify system acquistion and to obtain a committment to funding will normally cover many areas. Among these areas will be the following tasks:

- an analysis of traffic problems in the area, their trends and the require ments implied for new control equipment
- a summary of the maintenance problems and the traffic control limitations of existing control equipment
- an estimate of the benefits to be obtained from a new control system
- an analysis of any other changes that would be required in order to accomodate the new traffic control system (e.g. staffing changes, new quarters)
- background on computerized traffic signal control systems and their characteristics, and the recommendations of an approach for acquiring such a system
- financial requirements, cash flow, and proposed schedule for computer acquisition
- an evaluation of the role of consultants and others in the proposed project
- subjective considerations

Although it is feasible that municipal staff could undertake all of the above tasks, it is normal that consultants be used because of departmental work loads, lack of familiarity with computerized control systems and procurement options, and the desirability of obtaining special expertise and objective analysis in determining system need. In cases where the need is obvious and urgent, certain of the above steps may be eliminated.

7.2 Selection of System Requirements

The selection of required features for the computer system is normally made by the municipality after discussions with system suppliers or the consultant chosen for the project. The analysis undertaken can be minimal, with engineering judgement and subjective considerations determining the system requirements or a methodical very rigourous approach can be undertaken.[1] The results of this process whether it be the subjective approach or the rigorous approach will lead to a requirement for a system that could have several unique features on the one hand or could have a number of elements in common with existing systems.

Clearly, off-the-shelf system are potentially less costly than "made-to-measure" systems because systems engineering and software design costs can be distributed among several different systems.

Most system suppliers have successfully implemented a number of control systems, each having unique features, with the result that today, off-the-shelf systems represent the best features of all systems which preceeded them. The requirements of most small and medium-sized cities can be met through an off-the-shelf system. However, all off-the-shelf systems are not the same, and the determination of essential or required system features can favour some systems at the expense of others. Additionally, as the number of required features and their complexity increases the cost and the complexity of the system increases.

The major concern during this stage of procurement is to define all required features of the system without defining one that is unnecessarily complicated and doing this in such a way that a reasonable number of manufacturers will be able to bid on the required system.

---

[1] An approach for selecting traffic control systems, NCHRP Project No. 3-18(3), JHK & Associates, March 1977.

7.3 Preparation of Tender Documents

Specifications can be developed by municipal staff, procured from manufacurers or prepared by consultants. Because of normal work load, municipal staff are not usually able to devote sufficient time to this task. Moreover, it is usually more efficient if this task is undertaken by someone with specific experience in the area. The specifications provided by manufacturers are usually specific in several key areas such that the manufacturer who provided the specification has a great advantage over other manufacturers during the tendering process.

A specification that is too loose will allow a great number of different systems to be bid and the danger exists that the lowest price system will not be the most cost-effective one yet the city will be obliged to accept it. On the other hand, specifications that are too rigid will exclude most or all off-the-shelf systems and will result in a system that is too costly because of a lack of competition, the requirement for a large amount of unique system development, or both.

Pre-qualification of bidders is frequently undertaken during this process. Potential bidders are normally required to show that they have developed either an operational or prototype traffic control system which is capable of performing certain required functions.

An important point in specification development is the concept of the prime contractor who is responsible for all elements of the system to be provided, even those elements which are subcontracted to others. This relieves the municipality from the onerous task of deciding (and sometimes having to prove) exactly who is responsible for problems which invariably occur.

Engineering plans are required to complete the tender documents. Plans provide the detailed information on the work to be undertaken. Their purpose is two fold:

1. To allow potential system suppliers to make an accurate cost assessment.
2. To make the supervision of the contractor's work less difficult during installation.

The amount of plan preparation required will be determined by the following factors:

1. The agency performing the work.
   If municipal forces are to be used for installation activities, the requirements for detailed plans is less and it is not necessary that the plans be included with the tender documents. If the telephone utility is to handle the installation of conduit for signal interconnection, detailed plans do not need to be prepared by the municipality as a rule.

2. The amount of work to be undertaken.
   If the number of new detector installations, new controller cabinets and new signal hardware is large then extensive plan preparation may be required if contractors are to carry out the work.

3. The desire to transfer activities from the specification preparation phase to the installation phase.
   Instead of using drawings to show the exact locations of detectors and the related necessary construction work, it is possible to leave details vague and ask for bids based on x feet of conduit, y feet of trenching etc. Although this simplifies the preparation of tender documents, it does require either that plans be prepared at a later date or that the work of the contractor be monitored very closely.

4. The ability to use typical plans.
   If all controllers and cabinets are of a single type, it is not necessary to prepare separate diagrams for each controller and cabinet. As the number of different controllers and cabinets increases the number of required diagrams increases.

5. The amount of work required for the master site preparation.
   The requirement for additional work to prepare the location of the computer is dependent upon the space and environmental needs of the computer system and the extent to which these can be met without modifying existing walls, floors, air conditioning and power feeds.

Site plans can be prepared in functional form during specification preparation so that the successful bidder can provide complete engineering plans for the approval of the city during installation of the computer system.

7.4 Evaluation of Technical Proposals, Costed Bids, Contract Award

The evaluation of technical proposals involves a detailed examination of each bidder's proposal. Bidders will normally offer the alternatives which are the cheapest for them to provide. A group of municipal and consulting staff normally decides which elements of a proposal meet the intent of the specification and which do not. Frequently suppliers do not provide sufficient detail to allow reviewers to determine if the functional specification is met. In this case the bidder is reminded that the system provided must meet the specification in all respects.

The end product of this evaluation is a detailed reply to each bidder which indicates the acceptable and the unacceptable items in his technical proposal. Bidders whose systems meet the technical requirements are then invited to submit costed bids. When costed bid documents are received the first step normally undertaken is to verify that the lowest priced bid still meets the specifications in all respects.

If the lowest priced system does meet all specification requirements, the contract award process is normally straight forward. However, if the lowest priced bid does not meet the specification in some respects this bid is normally disqualified and the next lowest price bid is evaluated. If the deviation from specification is not considered serious, cost-benefit analysis may be undertaken in order to determine the most cost-effective system.

After contract award, a period of negotiation normally takes place between the municipality and the successful bidder in order to discuss the suitability of certain details of the proposed system. This is often difficult, since a detailed consideration a specific element of the proposed system may point out differences in interpretation of the system supplier's proposal. Most system suppliers have on staff individuals who are skillful at negotiation and it is desirable that the municipality avail itself of someone with these skills.

7.5 System Implementation and System Acceptance

It is desirable to have the system supplier assume overall responsibility for providing a working system. With "turn-key" systems this is accomplished by having the supplier with his subcontractors perform all

the required tasks leading to an operational system. Such "turn-key" systems place all the responsibility for implementation sucess on the supplier but may result in higher overall cost than is otherwise achievable. An examination of implementation tasks reveals a number of tasks which may be more economically carried out by local forces under the direction or supervision of the supplier at significant cost savings.

The following are the major tasks that must be undertaken in the implementation phase.

1. Controller modification and ICU installation
2. Detector installation
3. Communications line installation or Bell hookup
4. Signal timing plan preparation
5. Data base development
6. Master facility preparation
7. Master controller installation
8. Training
9. System integration
10. System acceptance

Clearly, master controller installation and system integration (Tasks 7 and 9) are the responsibility of the system supplier. When Bell lines are used Task 3 becomes the sole responsibility of Bell. The telephone company generally prepares any engineering plans that are required, and carries out the necessary construction. The municipality, however, is billed for the full cost of such work. Where the municipality wishes to use its own cable and conduit, engineering and construction work can be carried out by the system supplier but more usually will be done directly by municipal staff or outside contractors under municipal supervision.

Although controller modification and ICU installation, detector installation and master facility installation (Tasks 1, 2 and 6) may form part of the overall procurement contract it again is generally more cost effective and of benefit to the municipality to have the work done by local contractors under municipal supervision or with municipal participation. Where municipal staff can provide close supervision of the work, substantial savings can result from the elimination of the need to prepare detailed plans. The experience gained by maintenance and electrical staff in modifying controllers and installing ICU's proves useful in later system

operation. While the municipality may wish to carry out controller modification and ICU installation (Task 1) with local forces for reasons of economy and to gain valuable knowledge, it may at the same time still wish to place responsibility for overall system performance upon the contractor. This may be achieved by requiring the system supplier to prepare drawings and instructions describing the work to be carried out in Task 1. The supplier can be obligated to inspect and approve local installation procedures and practices and indicate his satisfaction if the work meets his requirements. The supplier is thus made responsible for local intersection equipment operation while not doing the work himself.

Signal timing plans may be prepared (Task 4) by local staff or by consultants under a separate contract. Data base development (Task 5) involves the preparation of signal timing and intersection phasing tables. This information is then entered by the system supplier into the computer's memory bank.

Training (Task 8) is provided by the system supplier and includes instruction to operators, traffic engineers and maintenance staff.

System acceptance (Task 10) includes the final testing, and commissioning of the system, ending with the formal acceptance of the system by the municipality. Acceptance testing includes the demonstration of all the functions included in the specifications, and normally a specified period of trouble-free system operation. Acceptance test procedures are submitted by the system supplier as part of his proposal. In the planned MTCS Project, the system consultant will review and approve the proposed acceptance test procedure and also witness final acceptance testing. Should final acceptance not be successful, the supplier will be obliged to cover the cost of additional retests. This approach minimizes acceptance testing costs and at the same time provides incentive for the system supplier to solve all outstanding problems before attempting to carry out final acceptance testing.

The above brief description indicates that many of the installation and acceptance tasks can be carried out by local forces. In this way the need for consulting services is minimized and costs are kept to a minimum while the system supplier still retains responsibility for overall system performance.

8. CONCLUSIONS

The following conclusions were reached by study staff following the examination of the traffic control requirements of Ontario municipalities and the investigation of available traffic control systems:

Municipal Status

Responses to the MTCS Municipal Questionnaire revealed the following:

1. A number of existing centralized traffic control systems operating in the Province are obsolescent and are increasingly more difficult and expensive to maintain.

2. Several cities lacking centralized traffic control systems perceive a need for such systems to meet increasing vehicular demand resulting from municipal growth.

3. Several new systems will have to be installed in the next two to three years.

4. Several additional systems will have to be installed in the next three to five years.

5. No unusual or unique traffic control requirements were indicated by any municipality, making possible the MTCS goal of a standard system for Ontario municipalities.

6. Municipalities indicate a desire for the Ministry to provide technical guidance and support in the selection, installation and operation of computerized traffic control systems.

MTCS Requirements

Analysis of returned questionnaires and contact with municipal staff led to the identification of the following MTCS requirements:

1. The system must provide two-way communications.

2. The system must be capable of 24 hour-a-day unattended operation.

3. The system must be such that staff untrained in computer operations be able to operate it.

4. The system must be easily expansible to accommodate anticipated network growth.

Available Systems

When examined in light of the above as well as other identified traffic control requirements it was found that:

1. Several computer-based systems available off the shelf meet the MTCS requirements.

2. The installed cost of computerized traffic control systems is approximately $5000 to $6000 per controlled intersection.

MTC Role

The Ministry has a positive role to play in the coordination of the acquisition of computerized traffic control systems by the Ontario municipalities.

9. RECOMMENDATIONS

The recommendations listed below are based on the conclusions reached in this study. The first four recommendations have been accepted by the Ministry and participating municipalities and were in the process of being carried out at the time of printing of this report.

1. The Ministry should proceed with Phase II of the MTCS Project to assist the Municipalities of Waterloo, Durham and Brantford to procure computer-based traffic control systems.

2. The MTCS Project should led to the joint procurement of three systems from one supplier. Tenders should be based on a single functional specification developed jointly by the three municipalities and MTC.

3. The Project should produce specifications and procedures that may be used in future system procurement programs.

4. A seminar should be given to acquaint municipal traffic engineers as well as local traffic consultants with the MTCS Project and computerized traffic control in general.

5. The MTCS Project should continue into Phase III, which will:
   a) Evaluate the performance of the first installed systems as well as provide on-going assistance to the three municipalities to take full advantage of the traffic control capabilities of their new systems.
   b) Encourage and assist other Ontario municipalities in the acquisition of computer-based systems.
   c) Develop a method for producing optimum signal timing plans using readily available computer-accumulated traffic data.
   d) Undertake research into more effective network control strategies.
   e) Examine ways to further reduce the cost of hardware associated with computerized traffic control.
   f) Encourage participation of Canadian industry in supplying future hardware needs.

10. BIBLIOGRAPHY

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2. Selecting Digital Computer Signal Systems, U.S. DOT, FHWA Report No. FHWA-RD-72-20.

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Regional Municipality of York
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Appendix A, Glossary of Terms

Assembly Language - Computer language understood only by the computer for which it is written. More efficient than FORTRAN but difficult to learn to use. A large proportion of traffic control programs are written in assembler.

Background program - A low priority program that is executed only when higher-priority programs are not using the system resources.

Centralized control - Form of traffic signal control in which the ability to make control decisions and to issue control commands in placed at one location.

Compiler - A computer program used to translate a source (higher level)language program into a machine language program.

Control subarea - Subdivision of a single control area, generally operating under one timing plan.

CPU - The CPU (Central Processor Unit) is the brains of any computer, containing the logic to carry out the programmed instructions. In a microprocessor the CPU is generally housed in a single chip.

Critical Intersection Control (CIC) - Form of cycle-by-cycle split allocation used at selected signalized intersections within a closed network of signalized intersections.

CRT - Cathode ray tube. An electronic vacuum tube with a screen for visual display of output data in alphanumeric or graphical form.

Disc - A device for storing large amounts of digital data in a permanent form. The storage device resembles a phonograph record. Information is recorded as magnetized bits on the disk.

Electromechanical controller - A controller which performs its function by having electrical impulses cause mechanical actions to take place.

FDM - Frequency Division Multiplexing is a method of transmitting several channels of data over one communications line through a multiplexing technique using frequency separation.

First Generation Control - Encompasses a number of traffic-responsive traffic control strategies where plans are selected from among a number of plans, every 15 to 30 minutes based on measured traffic parameters.

Floppy disk - An inexpensive, reliable, lower capability disk. See Disk.

Force-off - Commercial coming from an external source which causes an actuated controller to terminate the active phase, and to go to the next phase in the signal sequence requesting right of way.

Foreground program - A high-priority computer program, usually a real-time program, that pre-empts system resources whenever it requires execution.

FORTRAN - High level computer language accepted by all minicomputers. Some traffic control programs such as UTCS are written in FORTRAN. Language is relatively easy to learn to use.

Frequency shift keying (FSK) - A method of frequency modulation whereby ON/OFF (MARK/SPACE) information is represented by transmission of tones of different frequencies. Two- frequency shift keying (SFSK) uses one tone for MARK and another for SPACE. Three-frequency shift keying (3FSK) adds a third tone for the IDLE condition when neither MARK nor SPACE is being transmitted.

Full Duplex - In communications, means the simultaneous two-way independent transmission. Requires two pairs of communication lines. Contrast with half-duplex.

Functional specifications - Those specifications which only describe the general manner by which a control system shall operate.

Half-duplex - In communicatoins, means that two-way transmission in opposite directions is possible, but not simultaneously. Slower than full duplex. Requires one pair of communication lines.

Interconnected signal system - A number of intersections which are connected by direct wire, radio signal, or some other means to affect traffic progression.

Interval - The part or parts of the signal cycle during which signal indications do not change.

Isolated controller - Any controller whose operation is unaffected by any other controller or supervisory device.

Local controller - A controller supervising the operation of traffic signals at a single or two closely-spaced intersections.

Loop detector - A vehicle detector consisting of a loop of wire imbedded in the roadway, energized by alternating current and producing an output circuit closure when passed over by a vehicle. Sometimes referred to as an inductive loop.

Machine Language - The language of 1's and 0's used by computers. All higher level languages are translated by the computer into machine language before being stored in memory and used.

Magnetic detector - A vehicle detector imbedded in the roadway which makes use of both the earth's magnetic field and the magnetic change created by the passage of a vehicle over the detector to produce an output circuit closure.

Magnetic tape - A tape with a magnetic surface on which data can be stored by selective polarization of portions of the surface.

Magnetometer detector - Similar to a magnetic detector, but energized with an electromagnetic field, and capable of measuring volume or presence.

Master controller - A controller supervising the operation of several local controllers to coordinate offsets, dial transfer, flashing operation, etc.

Master-secondary controller - A controller that serves as a local controller at one intersection in addition to serving as a master controller for an interconnected system.

Measures of effectiveness (MOE's) - Indicators of system performance.

Microprocessor - Medium to high speed electronic computing device that is capable of performing simple arithmetic and logical decision-making operations. The key characteristics of the microprocessor are its small physical size and its low cost. Current microprocessors are generally packaged in from one to four integrated circuit packages (commonly called chips). A typical microprocessor can perform basic arithmetic operations such as add and subtract, and make simple decisions such as two-way branching following the comparison of two numberical values. Most can also store limited amounts of data in internal registers.

Mini-computer - A 16 bit or 32-bit computer which has many of the capabilities of large general purpose computers but cost significantly less. More powerful than microprocessors. Suitable for computer-controlled traffic control systems.

Modem - A contraction of modulator/ demodulator. When transmitting data a modem converts digital data into a form suitable for transmission over a communications link and, when receiving data, the modem reconstructs the data from the received signals. See also Modulation, Demodulation.

Offset - The time relationship expressed in seconds or percent of cycle length, determined by the difference between a defined interval portion of the coordinated phase green and a system reference point.

On-line - Term used to describe a computer system and the peripheral equipment or devices in the system in which the operation of the peripheral equipment or devices are under the control of the central processing unit.

Operating system - All of the programs which extend the capabilities of the computer hardware and which made the hardware more easily usable. This usually includes the function of controlling and scheduling execution of programs, controlling input-output, data management, language translation and related services.

Phase - A portion of a signal cycle during which an assignment of right of way is made to a given traffic movement. A phase is composed of green and yellow intervals.

Phase shift keying (PSK) - A method of digital data tramsmission wherein binary information is represented by changes in the phase of a sinusoidal carrier signal.

Pretimed controller assembly - A controller assembly for the operation of traffic signals with predetermined fixed cycle length, fixed interval duration, and fixed interval sequence.

Real-time, traffic-responsive control system - Traffic control system which evaluates and selects control tactics continuously on the basis of current measures of traffic conditions.

Request for proposal (RFP) - A written document inviting prospective bidders to submit a project proposal.

Second-generation control - On-line timing-plan generation wherein new timing plans are generated approximately every 15 minutes.

Semi-actuated traffic controller assembly - A type of traffic-actuated controller assembly in which means are provided for traffic actuation on one or more but not all approaches to an intersection.

Signal Optimization - A process carried out to generate signal settings that will minimize some objective function such as travel time, delay or stops. A number of computer programs such as TRANSYT, SIGOP, SIGRID exist to perform the function.

Signal timing - The amount of time allocated for the display of a signal indication.

Software - All of the programs executed on a computer system. Contrasted with Hardware.

Specifications - Written documents describing minimum requirements for items of work, materials, equipment, etc.

System controller - A controller designed to operate with a central computer. Contains integral communications and offers more flexible control capabilities than other controllers.

Systems engineering - An approach which views an entire system of components as an entity rather than simply as an assembly of individual parts; i.e., a system in which each component is designed to fit properly with the other components rather than to function by itself.

TDM - Time Division Multiplexing is a method of serial data transmittion through a multiplexing technique using time separation.

APPENDIX B
MUNICIPAL TRAFFIC CONTROL SYSTEMS (MTCS)
QUESTIONNAIRE

1.0 General

1.1 Name of person responsible for completing questionnaire.

____

1.2 Employed by Municipality of

____

1.3 Name of Department responsible for traffic operations.

____

1.4 Position of person completing questionnaire.

____

1.5 Telephone: ____________________

1.6 Address: ____________________

____

____

1.7 Above government has traffic control signal responsibility for what towns, cities or municipalities with populations over 20,000 or more than 8 signalized intersections?

Name	Population

*** Please complete one set of the questions 2.1 to 5.6 for each place named in 1.7 above

2.0 City Physical Characteristics

2.1 Name of municipality ______________________

2.2 Area in square miles ______________________

2.3 Number of signalized intersections within municipality?
Regional ____________
Local ____________
MTC ____________

2.4 Is there a CBD? ____________________

2.5 Number of signalized intersections in CBD? ________

2.6 We would like some information about the location of Traffic Control Equipment. On a map showing the city street system, drawn to scale:

(a) Indicate the location of all signalized intersections.

(b) Denote and reference each interconnected signal system.

(c) Give the location or possible future location of any central master controller.

(d) Show any railway level crossings.

2.7 Does the municipality allow or favour underground or over-head wiring?

Underground: allow ______ favour ______

Overhead: allow ______ favour ______

Note: If the above municipality has fewer than 9 signalized intersections and these signals are not part of an arterial network you may, if you wish, answer only questions 3.3 and 4.5 of the remaining questions.

3.0 Existing Traffic Conditions

3.1 Please give a brief description of the major traffic flow patterns and arterials or supply a copy of the most recent traffic volume data for the municipality if available.

3.2 Indicate the location and approximate frequency, times and duration of recurring traffic congestion. Please give levels of service where available.

3.3 Please comment on any peculiar traffic problems in your city.

e.g. - heavy traffic in industrial area at quitting times
- heavy traffic following sporting events
- heavy rail traffic at level crossings

4.0 Hardware Inventory

4.1 Please indicate below the major types of controllers being used in the field.

Manufacturer	Model	Quantity

4.2 List any other control equipment, such as master controllers, MTSS, or other central control system. Please describe system and type of interconnection used and give year of installation. How effective is the equipment?

4.3 Please give a brief description of any interconnected system referenced in 2.6(b) and not mentioned above.

4.4 Does the traffic office have access to a computer for traffic data handling or for scientific programming use?

Yes ______ No ______

If YES, give particulars below:

Data handling ____________________________

Scientific programming ____________________

4.5 Please indicate the effectiveness of the present traffic control equipment to meet the traffic control needs of your municipality.

4.6 How many new signal installations are planned for:

1977 ______ 1978 ______

5.0 Operations

5.1 What is your present staff size?

(a) Traffic equipment repair and maintenance staff

full time ________

part time ________

Man hours spent on traffic signal or control functions by above staff ________ man hours

(b) Traffic Technicians ________

(c) Traffic Engineers ________

(d) Others involved in traffic control - specify ________________ ________________

________________ ________________

________________ ________________

5.2 Where questionnaire is being answered by the regional traffic office, please indicate size and scope of the traffic signal operations performed by any area municipality traffic office which is within the regional municipality. (i.e. Number of people, budgets, responsibilities)

5.3 What is the total traffic signal control budget for new signal installations and signal maintenance:

	Municipal Cost	MTC Subsidy	Total
1975	________	________	________
1976 (Projected)	________	________	________

5.4 Please give the name of any local transit operating authority active in the municipality:

____

5.5 Name, address and telephone number of person to contact for further transit related questions:

____

____

____

APPENDIX C -- QUESTIONNAIRE SUMMARY

City/Region[1]		Population (1000)	Area (sq. miles)	Budget ($1000)	Traffic Problems[2]	System Effectiveness[3]	Number of Traffic Signals: Total	Inter-Connected	CBD	CBD Interconnected
Ajax	-D	20.7	25.2	-	I	B	11	5	5	5
Barrie		34.0	10.8	50.0	C	B	29	11	3	2
Belleville		35.0	12.0	89.9	I,RR	C	33	22	13	13
Brampton	-P	105.0	110.0	107.0	C	B	35	8	8	8
Brantford		66.9	20.3	78.0	I	C	53	29	16	15
Brockville		20.0	9.4	17.0	I	B	9	0	3	0
Burlington	-H	102.0	71.0	274.0	I	B	49	10	6	0
Cambridge	-W	71.5	44.0	71.8	I	C	46	14	10	6
Chatham		38.0	9.0	4.1	I,RR	C	23	8	6	5
Cornwall		48.0	31.0	120.9	I,C	C	31	0	6	0
Dundas	-HW	19.6	10.2	2.6	-	A	9	6	6	6
Guelph		70.1	25.2	68.4	I,RC	B	67	29	18	13
Kingston		60.5	11.0	89.0	I,RC	B	66	0	22	0
Kitchener/Waterloo	-W	181.8	77.2	238.7	I	C	153	75	34	34
London		244.0	68.2	630.0	I	B	130	42	31	31
Markham	-Y	55.6	45.0	39.6	I,RC	A	15	2	7	2
Mississauga	-P	225.0	110.0	200.0	I	B	126	4	0	0
Newcastle	-D	31.6	22.4	4.2	-	A	3	0	0	0
Newmarket	-Y	24.7	16.0	28.6	RC,RR	B	14	6	0	0
North Bay		51.0	126.0	21.5	I,C	C	33	0	15	0
Oakville	-H	68.2	58.0	134.7	I,C,RR	C	40	6	11	0
Orillia		22.6	8.2	39.0	I,RR	B	21	4	10	3
Oshawa	-D	106.0	56.0	108.8	I,RC	B	78	47	16	16
Owen Sound		19.3	8.0	15.0	I,C	C	13	0	6	0
Peel		377.0	525.8	280.0	I,C,RR	C	69	0	0	0
Peterborough		59.4	19.9	47.0	I,RC	B	64	14	14	14
Pickering	-D	27.8	90.4	15.3	-	A	11	0	0	0
Richmond Hill	-Y	34.5	35.0	35.1	C	C	22	6	8	6
St. Thomas		27.0	10.0	26.5	C,RC	B	14	4	6	4
Sault Ste. Marie		78.0	89.0	99.7	I,RC	C	71	37	24	24
Sarnia		54.9	18.3	45.5	I	B	54	22	7	7
Stratford		25.0	7.3	16.5	I,C,RC,RR	B	15	2	7	2
Sudbury	-S	97.0	113.0	99.0	I,C,RR	B	66	32	21	17

City/Region[1]	Population (1000)	Area (sq. miles)	Budget ($1000)	Traffic Problems[2]	System Effectiveness[3]	Number of Traffic Signals			
						Total	Inter-Connected	CBD	CBD Interconnected
Thunder Bay	109.0	156.0	70.6	I,RR	B	77	28	23	22
Timmins	44.0	1225.0	15.0	I	C	18	11	11	11
Whitby -D	28.0	56.8	20.9	C,RC	A	15	4	3	0
Windsor	200.0	49.0	246.8	I,RC,RR	C	150	28	29	8
Woodstock	26.0	9.0	18.5	I,RC	C	15	0	5	0
Total						1748	516	410	274
Fort Erie[4]	23.0	29.2				15			
Niagara Falls[4]	68.0	106.0				46			
Port Colborne[4]	20.5	32.0				11			
St. Catharines[4]	120.0	188.0				79			
Thorold[4]	15.0	70.0				16			
Welland[4]	45.0	36.0				34			

Notes:

1. Regional Municipalities are designated as follows:
   D = Durham   Y = York   H = Halton
   W = Waterloo   P = Peel   HW = Hamilton-Wentworth
   S = Sudbury

2. I = Industrial Congestion
   C = Commercial Congestion
   RC = Recreational Congestion
   RR = Railway Crossing Problems

3. A = Good
   B = Adequate
   C = Needs Improvement

4. No information received from the Regional Municipality of Niagara.

City/Region	Arterial Signals[1] Number[2] of Systems	Inter-Connected Systems	Number of Signals	Inter-connected Signals	Isolated Signals	MTC[3] Fixed T.	MTC[3] Act.	Controllers (existing/future)[4] Electro. Mech. Fixed T.	Electro. Mech. Act.	Solid State Fixed T.	Solid State Act.
Ajax -D	0	0	0	0	6	0	4	6	1	0	0/2
Barrie	2	1	10	7	16	0	3	13/2	13	0	0
Belleville	4	2	13	6	7	0	0	23	0	0	10
Brampton -P	2	0	9	0	19	0	0	21	4/4	0	11
Brantford	3	2	15	7	22	0	0	51/3	1	0	0
Brockville	0	0	0	0	6	0	0	6	0	0	0
Burlington -H	3	1	24	10	18	0	5	6	14	2	21/8
Cambridge -W	2	1	11	6	25	0	0	32/1	8	0	6/4
Chatham	2	1	7	3	10	0	0	13	9	0	1/2
Cornwall	4	0	17	0	8	0	0	29/1	1/1	0	1
Dundas -HW	0	0	0	0	3	0	0	8/2	1	0	0
Guelph	3	1	21	5	28	5	2	46	12/4	0	2
Kingston	3	0	13	0	31	0	0	52/2	0	9	5/2
Kitchener/Waterloo-W	7	3	32	12	87	0	6	113/4	32/2	0	0/1
London	7	0	44	0	55	0	0	80/2	23	0	27/8
Markham -Y	0	0	0	0	8	1	6	4/1	0	0	4/2
Mississauga -P	4	1	14	4	112	0	15	48	10	0	0
Newcastle -D	0	0	0	0	3	1	0	2	0	0	0
Newmarket -Y	2	2	6	6	8	0	4	8	0	0	2/2
North Bay	2	0	6	0	12	0	7	21/2	4	0	1
Oakville -H	1	1	6	6	23	0	4	4	0	0	32/4
Orillia	0	0	0	0	11	0	4	12/2	5	0	0
Oshawa -D	5	5	22	22	40	0	1	66/1	6	0	5/2
Owen Sound	0	0	0	0	7	0	0	11/2	1	0	1/1
Peel	6	1	30	5	39	0	29	36	15	0	18
Peterborough	2	0	6	0	44	0	0	58/2	0	0	6
Pickering -D	0	0	0	0	11	0	8	1	0	0	2
Richmond Hill -Y	0	0	0	0	14	2	6	11/3	0	0	3

City/Region	Arterial Signals[1] Number[2] of Systems	Inter-Connected Systems	Number of Signals	Inter-connected Signals	Isolated Signals	MTC[3] Fixed T.	MTC[3] Act.	Controllers (existing/future)[4] Electro. Mech. Fixed T.	Electro. Mech. Act.	Solid State Fixed T.	Solid State Act.
St. Thomas	0	0	0	0	8	0	1	12	1	0	0
Sault Ste. Marie	2	2	11	11	36	0	0	64	2	0	5/3
Sarnia	5	3	21	15	26	0	3	47/2	0	0	4
Stratford	0	0	0	0	8	0	0	4	11	0	0
Sudbury -S	4	2	22	15	23	0	5	28	0	2	31/2
Thunder Bay	3	0	13	0	41	0	11	65/5	1	0	0
Timmins	0	0	0	0	7	0	2	16	0	0	0/1
Whitby -D	1	1	8	4	4	0	2	9	1	0	3
Windsor	8	1	62	20	59	0	0	80	47	5	18
Woodstock	0	0	0	0	10	0	0	13	2	0	0
Total	87	31	443	165	895	9	128	1149/37	225/11	18/0	219/44

Notes:

1. Arterial signals are defined as signals within a group at at least three signals such that no more than 3000 feet separate any two adjacent signals within the group.
2. Arterial systems are groups of arterial signals.
3. Refers to MTC signals operating within the municipality.
4. The first number (A of A/B) gives the number of controllers of the type indicated operating in January 1977. The second number (B of A/B) where given, indicates the number of such controllers the municipality intended to purchase in 1977.